EJECTA EXPERIMENTS AT THE PEGASUS PULSED POWER FACILITY

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Abstract

When a shock wave interacts at the surface of a metal sample "ejected matter" (ejecta) can be emitted from the surface at velocities larger than the sample velocity. The mass, size, shape, and velocity of ejecta varies depending on the initial shock conditions and the target's material properties. In order to understand this phenomena, diagnostics have been developed and implemented at the Pegasus Pulsed Power Facility (PPPF) located at Los Alamos National Laboratory (LANL). The facility provides both radial and axial access for making measurements. There exist optical, laser, and X-Ray paths for performing measurements on the target assembly located near the center of the machine. The facility can provide many mega-amps of current which are transported to a 5.0-cm diameter, 2.0-cm high aluminum cylinder. The current and associated magnetic field set up forces which implode the aluminum cylinder radially inward. As the aluminum cylinder reaches the appropriate velocity, it impacts a target cylinder. Due to this impact, a shock wave is set up in the target and eventually interacts at the inner surface of the target cylinder where ejecta are produced. A 1.5-cm diameter collimator cylinder located in the target cylinder is used to control the number of ejecta particles that arrive at the center region where ejecta measurements are made. Two diagnostic techniques for characterizing ejecta, in-line Fraunhofer holography and visible shadowgraphy are detailed in this report.

I. Introduction

Metals under shock-loaded conditions can lead to complex phenomena depending on varying properties of the material and initial shock conditions. In particular, if a metal is shocked, ejecta can be emitted from the metal surface as the shock wave interacts at the surface. Two diagnostics have been developed and are being applied on experiments conducted at the PPPF to characterize the ejecta. The first diagnostic, holography, is primarily used to provide three-dimensional imaging with the capability of measuring particles as small as 2 microns in diameter. The second diagnostic, visible shadowgraphy, provides a series of twelve spatially resolved images over time. In this report the experimental setup will be described and the

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14. ABSTRACT
When a shock wave interacts at the surface of a metal sample ejected matter (ejects) can be emitted from the surface at velocities larger than the sample velocity. The mass, size, shape, and velocity of ejects varies depending on the initial shock conditions and the targets material properties. In order to understand this phenomena, diagnostics have been developed and implemented at the Pegasus Pulsed Power Facility (PPPF) located at Los Alarnos National Laboratory (LANL). The facility provides both radial and axial access for making measurements. There exist optical, laser, and X-Ray paths for performing measurements on the target assembly located near the center of the machine. The facility can provide many mega-amps of current which are transported to a 5.O-cm diameter, 2.O-cm high aluminum cylinder. The current and associated magnetic field set up forces which implode the aluminum cylinder radially inward. As the aluminum cylinder reaches the appropriate velocity, it impacts a target cylinder. Due to this impact, a shock wave is set up in the target and eventually interacts at the inner surface of the target cylinder where ejects are produced. A 1.5-cm diameter collimator cylinder located in the target cylinder is used to control the number of ejects particles that arrive at the center region where ejecta measurements are made. Two diagnostic techniques for characterizing ejects, inline Fraunhofer holography and visible shadowgraphy are detailed in this report.

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diagnostics discussed. The goal of these experiments is to characterize ejecta for various target and shock conditions. Experiments similar to these have been performed at other facilities[1,2,3,4,5].

II. Ejecta Formation

Shock strengths of many hundreds of kilobars can be obtained in aluminum and tin targets at the PPPF. When the shock wave interacts at the target vacuum (gas) interface, ejecta can be emitted from the surface. In Fig. 1 possible defects in a metal are shown which can contribute to the formation of ejecta. Defects such as voids and inclusions allow density discontinuities to exist in the metal so that when a shock wave moves through that area the metal may break up. In addition to defects in the metal, grain boundaries can also be possible places for the metal to break up as a shock wave moves through the material. The figure also shows that if there are surface variations, microjets can be formed thus contributing to the amount of ejecta. In addition to material properties which contribute to ejecta formation, initial shock conditions such as shock wave strength and rise-time also contribute strongly in determining the amount and velocity of the ejected material. If the shock wave is strong enough, the material can melt. Once melted it has been found[1,6] that the amount of ejecta increases dramatically.

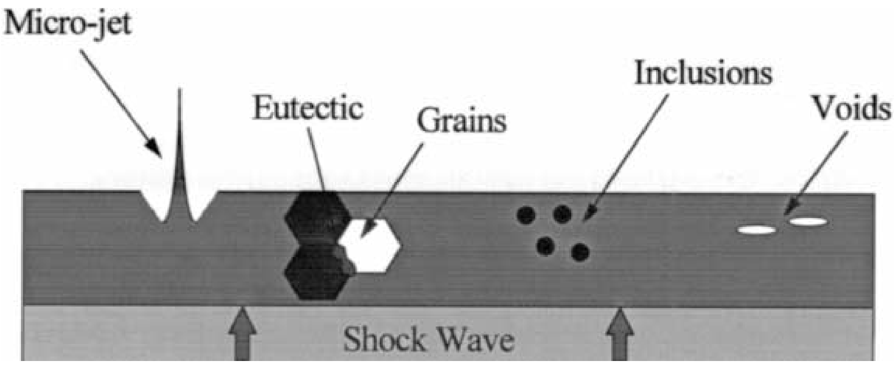

Figure 1: Illustration of possible ejecta formation processes. The shock wave is shown coming from the bottom. The shock wave can interact in the material causing the material to break up and be ejected out ahead of the material.

It is important that material and shock wave properties are well characterized for each experiment. The corresponding experimental measurements can then be correlated with those properties. A particular material property that is characterized for each experiment is the grain structure. Fig. 2 shows a photomicrograph of tin. The figure shows clearly the grain

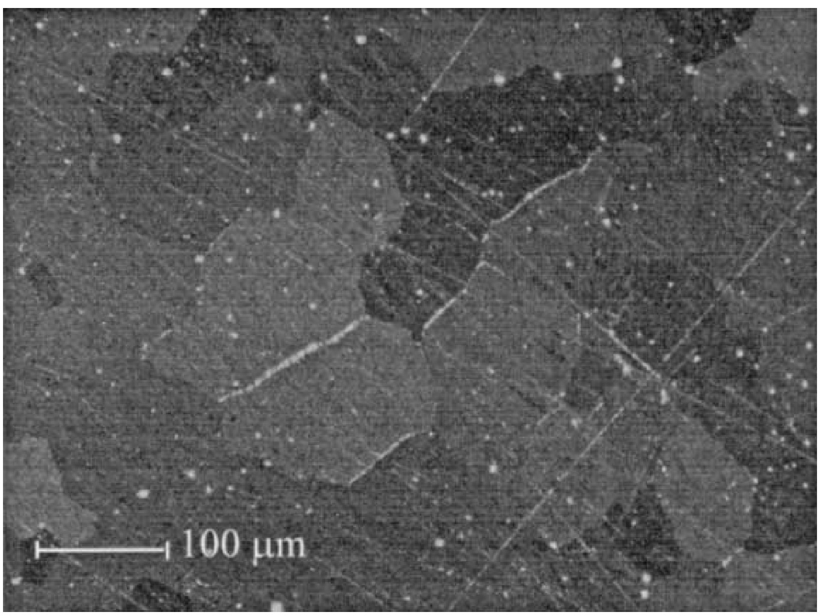

Figure 2: Photomicrograph of tin. The target has been etched to bring out the grain boundaries.

boundaries and an average grain size of 70 microns is measured.

III. Ejecta Measurements at the Pegasus Pulsed Power Facility

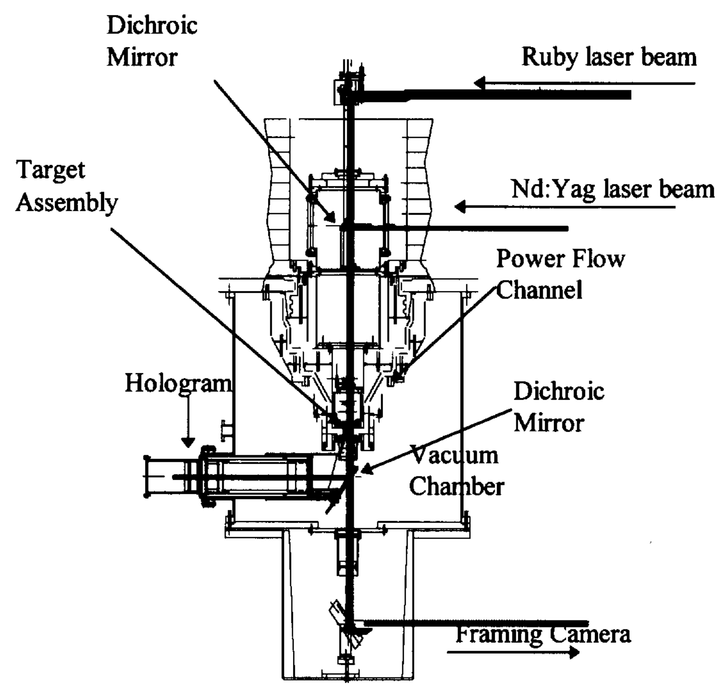

Figure 3: The experimental configuration at the Pegasus Pulsed Power Facility. Laser beams for the ejecta measurements are shown.

The PPPF provides current necessary to implode an aluminum cylinder to velocities of many mm/μsec. The experimental configuration is shown in Fig. 3. The figure shows the power flow channel which transports the electrical current to the center region of the vacuum chamber where the target assembly is located. This is the region where the ejecta physics experiments are performed. Both radial and axial access is available for making measurements. Fig. 4 shows a more detailed view of the target assembly area. The figure shows a 400-micron thick aluminum cylinder measuring 2.0 cm high and 4.8 cm in diameter which accepts the current and is driven cylindrically inward. This cylinder is called the liner driver. The target, a 400-micron thick cylinder measuring 3.0 cm in diameter, is shown inside the liner. For a typical experiment the aluminum cylinder is driven to a velocity such that a shock wave many hundreds of kilobars is generated inside the tin target. Finally, a collimator which is a tantalum cylinder with various cutouts is used to control the number of particles entering the area where the ejecta measurements are made. The area density (in the plane perpendicular to the cylinder surface) must be kept low enough so that the in-line Fraunhofer holography measurement can be effectively made.

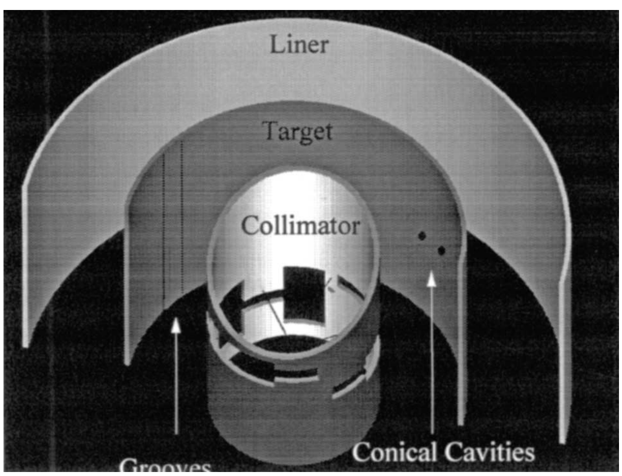

Figure 4: Target assembly. The liner accepts current from the power flow channel and is driven radially inward and impacts the target. The collimator controls the number of particles that enter the center region.

Various diagnostics are used to characterize the performance of the PPPF. Primarily these include current measurements performed using B-dot probes and Faraday

rotation technique[7,8]. In addition, one of the probes has proved useful in providing a trigger for the holography laser. The initial conditions for the ejecta experiment start once the shock wave is set up in the target cylinder. This time occurs about 9 microseconds (μs) after current has started to flow through the liner and the ejecta diagnostics are triggered about 3 μs later. If the ejecta diagnostics are triggered from the start of the current flow an error of +/- 100 nanoseconds (ns) can be expected due to uncertainties in the charging of the Pegasus capacitors. To improve the timing uncertainty, the B-dot signal is put through a high pass filter, which passes the high frequency induced signal that occurs when the liner impacts the target. This signal is shown in Fig. 5 as the long dash curve and occurs at about 9 microseconds where the zero of the time scale corresponds to the start of current flow. The figure also shows two other digitizer records. The solid curve is a gate that is used in coincidence with the laser trigger so as to prevent a pretrigger. Also shown in the figure is the actual laser monitor signal which records the laser light as it passes through the hologram.

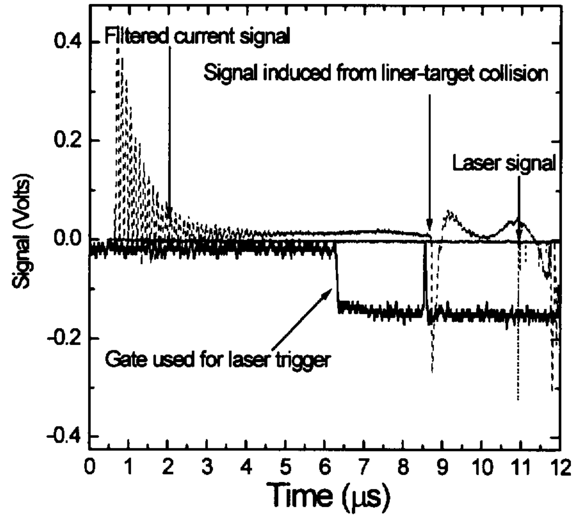

Figure 5: Digitized time records for the laser timing. A Gate is shown as the solid curve. The timing signal from the laser and the filtered B-dot signal are also shown.

A diagnostic that is used to measure the dynamics of the target assembly are three radial X-Ray units[9] used in conjunction with film to provide images of the cylindrical target assembly as it implodes. Fig. 6 shows a static image (at the top) and one of the three dynamic images (bottom) obtained on an experiment. The outer liner, target cylinder, and collimator are labeled in the top portion of the figure. The tantalum collimator completely absorbs the X-Rays and so is completely black. The lower figure shows the image obtained on the experiment. The target is seen to have moved inward from its original position, and some debris is left behind which is part of the aluminum liner. In addition to the X-Ray imaging, visible imaging is used to measure the

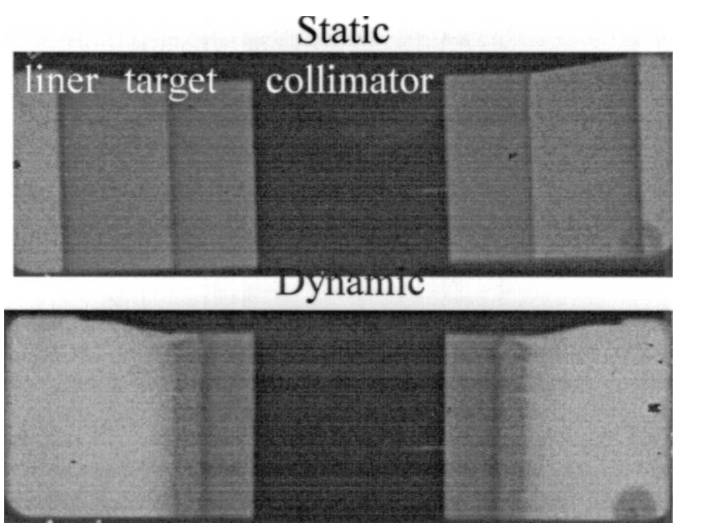

Figure 6: X-Ray image of target assembly. Image is viewing from the direction oriented radially out from the axis of the cylinders.

liner before it impacts the target. With the X-Ray imaging, visible imaging, and current probes, the target assembly dynamics can be accurately measured.

IV. Ejecta Diagnostics

Two primary diagnostics are used to measure the ejecta emitted from the shocked surface. These are: in-line Fraunhofer holography, and visible shadowgraphy. The in-line Fraunhofer holography has been described previously[4,10,11,12]. Fig. 3 shows how the laser beams for both of these systems traverse through the Pegasus vacuum chamber and the target assembly. Recently, a new optical relay system was designed and built to provide 1000 line-pairs/millimeter (lp/mm) resolution for an image plane with a 15 mm diameter. This lens relays an interference pattern produced in a plane near the ejecta to a distance 93 cm from this plane. The layout of this lens is shown in Fig. 7. After the interference pattern of the ejecta is recorded onto the hologram, the data is reconstructed optically and put into digital form. This process is described in Ref. 10. The shadowgraphy makes use of an 8-joule long pulsed ruby laser (500 μs FWHM). The wavelength of the ruby laser and the holography laser are 694 nm and 532 nm

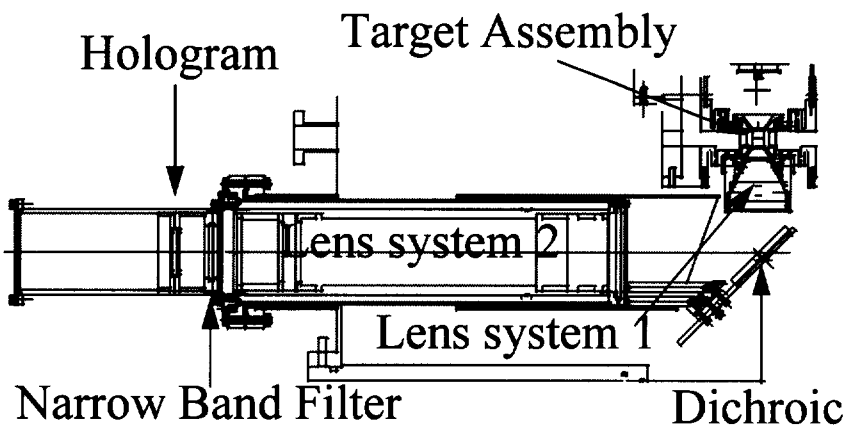

Figure 7: Lens system used for relaying the interference pattern. The hologram is located 93 cm from the image located in the target assembly. Dichroic mirror separates the Nd:Yag laser beam and the Ruby laser beam. The individual lens elements are not shown.

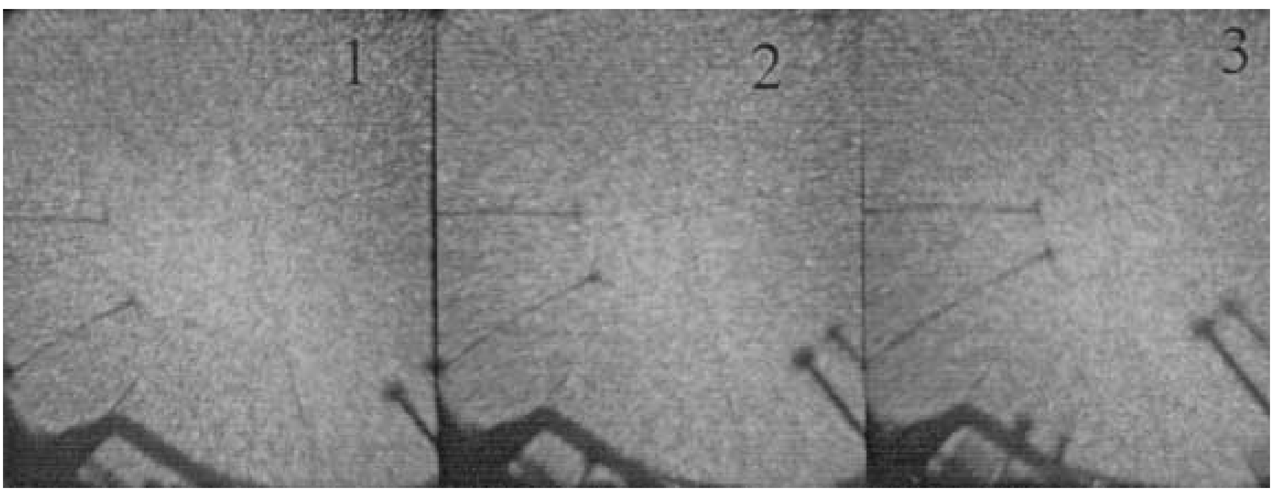

Figure 8: Shadowgraphs for three different times. Times increases from left to right. Micro-jets can be observed moving inward toward the center of the target assembly. Calibration cross hairs shown are 12 microns in diameter.

respectively. This allows dichroic mirrors to be used (shown in figures 3 and 7) so that both beams can be combined and transported collinearly on the axis of the target assembly, thus enabling both measurements to be made in the same spatial area. For the holography experiment, an additional narrow band filter is used in front of the hologram to prevent any unwanted light from exposing the holographic film, as shown in Fig. 7. Examples of the visible shadowgraphy are shown in Fig. 8. The figure shows three of twelve images obtained. The cross wires seen in the image are 12 micron wires. Micro-jets are seen to move radially inward

V. Conclusions

The in-line Fraunhofer holography technique and visible shadowgraphy experimental techniques have been developed to be used in conjunction for ejecta measurements. Both measurements are made for the same spatial area. The holography provides high-resolution, three-dimensional data over about 1 cm^3 for particles as small as 2 microns in diameter. The visible shadowgraphy provides spatially resolved images over a 170 mm^2 area with an optical resolution of around 100 microns, but features as small as 10 microns in diameter are observed in the shadowgram. The shadowgraphy typically provides twelve images in time where each picture is gated at 50 ns.

VI. Acknowledgments

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